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Project Report
Natural Attenuation Study
Ground Water, Surface Water, Soil and Sediment Investigation
Industri-Plex Superfund Site
Woburn, Massachusetts

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Notice

This document is intended for internal Agency use only. All research projects making conclusions or recommendations based on environmental data and funded by the U.S. Environmental Protection Agency are required to participate in the Agency Quality Assurance Program. This project was conducted under an approved Quality Assurance Project Plan. The procedures specified in this plan were used without exception. Information on the plan and documentation of the quality assurance activities and results are available from the Principal Investigator.

The following individuals are acknowledged for assistance in field sampling and laboratory analyses: Dr. Richard Wilkin, Frank Beck, Cynthia Paul (USEPA/ORD-Ada), Patrick Clark, Thomas Holdsworth (USEPA/ORD-Cincinnati), Tim Bridges (USEPA-Region 1 Laboratory) and personnel with ManTech Environmental Research Services Corp. under Contract 68-C-98-138.

1.0 Purpose of Study

This document provides an assessment of arsenic contamination within the Industri-Plex Superfund Site and GSIP Study Area. It fulfills the work objectives set forth in the Natural Attenuation Study Work Plan (NAS WP; Revision 2; September 14, 2000), which was developed from the proposal, 'Natural Attenuation of Arsenic in an Urban, Industrialized Watershed' (NAS Proposal), prepared by Dr. Robert Puls (EPA/ORD) for the Industri-Plex Superfund Site Remedial Project Manager, Joseph LeMay (EPA/Region 1). The purpose of this study was to 1) determine the migration mechanisms controlling arsenic transport at the Industri-Plex Superfund Site and the GSIP Study Area, 2) provide an evaluation of the potential role of natural attenuation processes in mitigating arsenic transport from the Industri-Plex Superfund Site and GSIP Study Area and 3) provide guidance for determination of reasonable, cost effective treatment technologies for a river/wetland in an urban watershed. USEPA Region I – New England agreed to partially fund the NAS WP in accordance with the August 18, 1999 memorandum entitled, 'Industri-Plex Superfund Site: Approval for ORD Arsenic Natural Attenuation Study.' The information derived from this report will be incorporated into the Industri-Plex Superfund Site, Operable Unit 2 (OU-2), Multiple Source Groundwater Response Plan (MSGRP), Remedial Investigation/Feasibility Study (RI/FS).

The primary role of EPA/ORD was to investigate the migration of arsenic from suspected source areas within the Industri-Plex Superfund Site into the Hall's Brook Holding Area (HBHA). Three goals were addressed as part of this investigation: 1) identification of the mobile form of arsenic in ground water, 2) identification of the processes controlling arsenic uptake onto HBHA sediments, and 3) evaluation of the stability of arsenic associated with HBHA sediments. This information serves as a basis for identifying the effectiveness of natural

attenuation within the HBHA to mitigate down gradient migration of arsenic into the Aberjona River and for evaluation of potential remedial alternatives.

1.1 Site Background

The Aberjona Watershed is an industrialized 65-km² watershed located in northeastern Massachusetts. The watershed boundary lies within the towns of Reading, Woburn, Winchester and Medford. The Aberjona Watershed extends to the Mystic Lakes, which drain into the Boston Harbor via the Mystic River. Historic industrial activities have resulted in contamination within the northern extent of the watershed. Specifically, activities at the Industri-Plex Superfund Site, a 245-acre industrial park located in Woburn, Massachusetts, resulted in the deposition of inorganic and organic contaminants in soils, sediments, and ground water. In response to public health concerns, a Record of Decision (ROD) for the Industri-Plex Superfund Site was signed in 1986, addressing on-site soil, sediment, and hot spot ground water contamination.

Contamination at the Industri-Plex Superfund Site was a result of historical industrial activity. From the mid - 1800s to the 1930s leather tanning was the dominant industry in Woburn, and the Aberjona and its tributaries served as the main conduits for tannery wastewater (Durant et al., 1990). During the same period, starting in the late 19th century, sulfuric acid and arsenical pesticide manufacturing took place near the headwaters of the watershed in an area now designated as the Industri-Plex Superfund Site (Aurilio, 1992). Estimates suggest that 270 metric tons of arsenic may still exist within the site boundaries (Aurilio, 1992). By-products from glue-manufacturing operations from 1934-1969 were disposed on site. It is hypothesized that leached degradation products from these materials has contributed to the mobilization of arsenic via the ground water from source areas to the HBHA (Davis et al., 1994).

The ground water beneath the Industri-Plex Superfund Site and HBHA in North Woburn has been designated as a non-drinking water source area by the state of Massachusetts. This designation may influence selection of remedial alternatives to address the contaminated soils, ground water, surface water and sediments. It is possible that most if not all ground water discharges to a wetland down gradient of the Industri-Plex Superfund Site. If true, this wetland area may sequester or retard down gradient transport of arsenic. However, there is uncertainty as to the forms of arsenic in the various environmental media, interactions between the surface water and ground water, and stability of arsenic-contaminated sediment in the HBHA. These uncertainties must be resolved prior to considering Monitored Natural Attenuation as a remedial action alternative for arsenic contamination at the Industri-Plex Superfund Site.

1.2 Summary of Field Activities

The field sampling activities and laboratory analyses performed under this study provide a current assessment of arsenic distribution in ground water, surface water, and sediments at the Industri-Plex Superfund Site and within the HBHA Pond. Site characterization was directed towards identifying the predominant chemical processes controlling arsenic migration to and sequestration within the HBHA. Field-based sampling was carried out over a period of 23 months to assess time-dependent trends in arsenic mobility within the Industri-Plex Superfund Site and GSIP Study Area. The data derived from this effort provides a means for 1) assessing the long-term assimilative capacity within the unconsolidated aquifer and the down gradient wetland, and 2) the potential for future mobilization of arsenic that is partitioned to soil/sediment solids.

Results from ground water, surface water, and sediment sampling and characterization are summarized and evaluated in the sections and appendices that follow. Collection of ground

water, surface water, and sediment samples was completed during the following dates: October 13-21, 1999; November 30 – December 3, 1999; March 27 – April 6, 2000; May 16-18, 2000; August 22-30, 2000; March 26 - April 14, 2001; May 11-17, 2001; and September 10-21, 2001.

Descriptions of field activities during these dates are documented below:

October 13-21, 1999. Initiated collection of snap shot ground-water samples to provide a limited degree of plume characterization so that fixed ground-water monitoring points could be optimally located within the aquifer to monitor potential attenuation of arsenic within the Industri-Plex Superfund Site and GSIP Study Area.

November 30 – December 3, 1999. Completed collection of snap shot ground-water samples to provide a limited degree of plume characterization so that fixed ground-water monitoring points could be optimally located within the aquifer to monitor natural attenuation effects. Installed fixed ground-water monitoring points TW01, TW02, TW03, TW04 below HBHA Pond sediments, and TW06-1,2,3, TW07-1,2,3, and TW08-1,2 adjacent to HBHA Pond perimeter (see Appendix A for locations). Initiated monitoring of Hall's Brook Holding Area (HBHA) Pond water column to determine ground-water discharge derived from the Industri-Plex Superfund Site.

March 27 – April 6, 2000. Installed fixed ground-water monitoring points TW05 (below HBHA Pond sediments), TW08-3, and TW10-1,2,3 (see Appendix A for locations). Collected ground-water samples from fixed monitoring points within the Industri-Plex Superfund Site and GSIP Study Area, and surface water and sediment samples from the HBHA Pond. Sample collection was carried out to initiate long-term monitoring of arsenic discharge from site-derived ground water, establish the physical distribution of arsenic in HBHA Pond sediments, and to provide

data to build a conceptual model for the potential attenuation of arsenic within the Industri-Plex Superfund Site and GSIP Study Area.

May 16-18, 2000. Sampled from fixed ground-water monitoring points and collected sediment samples from north end of HBHA Pond at Atlantic Avenue Drainway discharge. Sampling effort supported long-term monitoring of arsenic attenuation within Industri-Plex Superfund Site and GSIP Study Area.

August 22-30, 2000. Sampled from fixed ground-water monitoring points to support long-term monitoring of arsenic attenuation within Industri-Plex Superfund Site and GSIP Study Area.

Installed fixed ground-water monitoring points TW11, TW12, and TW13 adjacent to south bank of HBHA Pond.

March 26 – April 14, 2001. Sampled from fixed ground-water monitoring points and from HBHA Pond water column to support long-term monitoring of arsenic attenuation within Industri-Plex Superfund Site and GSIP Study Area. Collected additional sediments from HBHA Pond to assess potential time-dependent changes in arsenic distribution. Installed multi-level sampling station at north end of HBHA Pond (hereafter referred to as NML) to aid periodic monitoring of water column chemistry following the March high surface water flow event (see Appendix A for NML location).

May 11-17, 2001. Collected ground-water and surface water samples from north multi-level sampling station (NML) within the HBHA Pond for the purpose of establishing recovery of water column chemistry following the March high surface water flow event.

September 10-21, 2001. Collected ground water and surface water samples from fixed ground-water monitoring points and from the HBHA Pond. Completed monitoring of water column chemistry at the NML sampling station within the HBHA Pond for the purpose of establishing

recovery from the March high surface water flow event. Collected additional sediments from HBHA Pond to assess potential time-dependent changes in arsenic distribution. Data collection supported refinement of site conceptual model for attenuation of arsenic within the Industri-Plex Superfund Site and GSIP Study Area.

2.0 Site Monitoring Network

2.1 Snap-shot Ground-Water Locations

During development of the NAS Proposal, it was anticipated that the current extent of the arsenic ground water plume(s) would have been established by the Industri-Plex Site Remedial Trust (ISRT) prior to implementation of well installation and sampling under the NAS Work Plan. Unfortunately, ISRT had not implemented their Final Groundwater and Surface Water Response Plan (GSIP) to delineate the arsenic, toluene and benzene plumes on-site. Therefore, EPA/ORD conducted limited, snap-shot ground water sampling using Geoprobe direct push technology based on historical data in order to locate the current extent of the arsenic ground water plume before establishing fixed ground water monitoring locations for the NAS Work Plan. Landmarks referred to in the following discussion are illustrated in Figure A.1 (see Appendix A). The location of snap-shot monitoring points is illustrated in Figure A.2 (see Appendix A).

The concentrations of arsenic, benzene, and toluene detected at these monitoring locations are illustrated in Figure 1. In general, the concentrations of benzene and toluene were not elevated at snap-shot locations north of the Boston Edison Easement. The highest concentrations of benzene and toluene were observed at snap-shot locations bordering the northeast edge of the HBHA Pond. The highest benzene concentration (4780 ppb) was observed at sampling location A11 at a depth of 30.5 feet below ground surface (bgs). The highest toluene

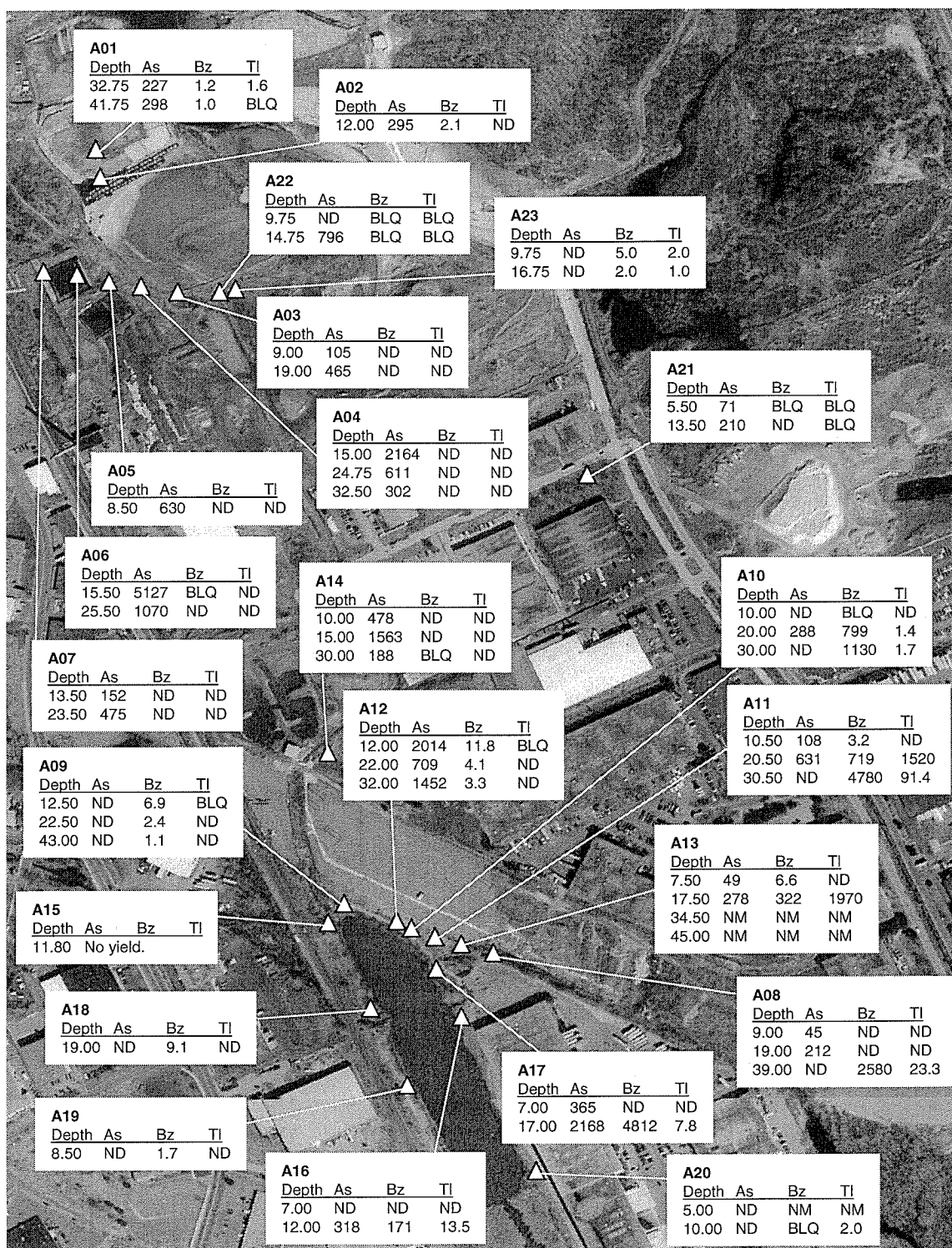
concentration (1970 ppb) was observed at sampling location A13 at a depth of 17.5 feet bgs. Based on the concentrations of these contaminants observed at all of the snap-shot monitoring points that bordered the HBH A Pond, it appears that the primary benzene/toluene plume is centered near the northeast edge of the HBHA Pond north of the 36 Cabot Road Building (formerly owned by Digital).

Elevated dissolved arsenic concentrations were more widely distributed throughout the Industri-Plex Superfund Site and GSIP Study Area. The highest concentration (5127 ppb) was observed at snap-shot location A06 at a depth of 15.5 feet bgs. This sampling point was located south of the West Hide Pile, but the concentration of arsenic observed within the hide pile boundary and immediately south of the West Hide Pile at similar depth was consistently less than 300 ppb (snap-shot locations A01 and A02). The arsenic concentration observed at location A06 suggests either 1) snap-shot location A06 coincides with the location of a source of contamination, 2) there is a source located between snap-shot location A02 and A06, or 3) an unidentified arsenic ground-water migration pathway from the West Hide Pile. Arsenic concentrations were also elevated (>200 ppb for at least one sampling depth) at locations A14, A12, A10, A11, A13, A08, A17, and A16. Snap-shot monitoring point A14 was located between the Industri-Plex Ground Water Treatment Building and the South Hide Pile. The remaining monitoring points bordered the northeast edge of the HBHA Pond and the parking lot north of the 36 Cabot Road Building (formerly owned by Digital). Only one location was sampled within the eastern portion of the Industri-Plex Superfund Site, and the concentration of arsenic was slightly elevated at this location (210 ppb). No arsenic was detected along the western edge and the southeast corner of the HBHA Pond.

The results from all sampling points confirm that elevated concentrations of arsenic at sampling locations adjacent to the northeastern edge of the HBHA Pond are derived from the Industri-Plex Superfund Site. Comparison of the arsenic concentrations observed for snap-shot monitoring locations with at least one depth showing >200 ppb As indicates that a major source of ground-water arsenic is derived from the western portion of the Industri-Plex Superfund Site for the area of coverage investigated. For example, locations A06, A04, A14, and A12 all had at least one depth with an arsenic concentration >1500 ppb. The variation of arsenic concentrations observed along a general north-south transect between the West Hide Pile and the HBHA Pond suggest that more than one arsenic source exists within this portion of the aquifer (locations and maximum As concentration: A06/5127 ppb, A14/1563 ppb, A12/2014 ppb).

Recent ground-water data collected by the ISRT confirm the presence of an arsenic plume derived from the western portion of the Industri-Plex Superfund Site (see Figure 1-3 in O'Brien & Gere Engineers, Inc., 2002). In addition, there are numerous locations within the aquifer down gradient from the East-Central Hidepile with dissolved As concentrations exceeding 100 ppb. However, ground-water monitoring transects south of the 36 Cabot Road Building (formerly owned by Digital) indicate either that ground water from this portion of the site discharges to the HBHA Pond or As is currently being sequestered on to aquifer solids in this region of the aquifer. Comparison of all ground-water data collected during 1999-2002 indicates that the HBHA Pond receives the majority of As originating from the aquifer at the Industri-Plex Superfund Site.

Figure 1. Aerial distribution of arsenic (As), benzene (Bz), and toluene (TI) concentrations from snap-shot ground water sampling locations for the Industri-Plex Site and GSIP Study Area. Reported concentrations are in units of parts per billion (ppb) for all contaminants and concentrations at each sampling depth are separated with a slash. See Appendices B and C for monitoring point locations and depths, respectively. ND = not detected, BLQ = below limit of quantitation. Image was derived from May 1995 aerial photograph obtained from MassGIS.



2.2 Fixed Ground-Water Locations

Based on the distribution of arsenic observed in the snap-shot monitoring points, permanent tubing wells were installed to capture the cross-section of the arsenic plume discharging to the HBHA Pond. One monitoring location was established within the Industri-Plex Superfund site boundary coincident with snap-shot location A14. This monitoring location served as a reference point for site-derived arsenic discharging to the HBHA Pond. The remaining tubing well locations were established between the northwest corner and the northeast edge of the HBHA Pond ending at the north end of the 36 Cabot Road Building (formerly owned by Digital). Within the GSIP Study Area, tubing wells were installed both on land adjacent to the HBHA Pond and below the sediments within the HBHA Pond. Locations of permanent tubing wells are documented in Figures A.4 and A.5 (Appendix A) and Tables B.1 and B.2 (Appendix B; locational data).

2.3 Hall's Brook Holding Area Pond

An effort was made to discern the impact of ground-water discharge on the chemistry within the HBHA Pond. This involved collection of surface water, ground water and sediments within and immediately adjacent to the HBHA Pond boundaries. A georeferenced bathymetric survey was carried out to establish depth to sediment within the HBHA Pond. Illustration of the data collection and resultant contour diagram of depth to sediment is shown in Appendix A (Figures A.6 and A.7, respectively). Details of the monitoring strategy are discussed below.

2.3.1 Water Column and Shallow Sediment Pore Water

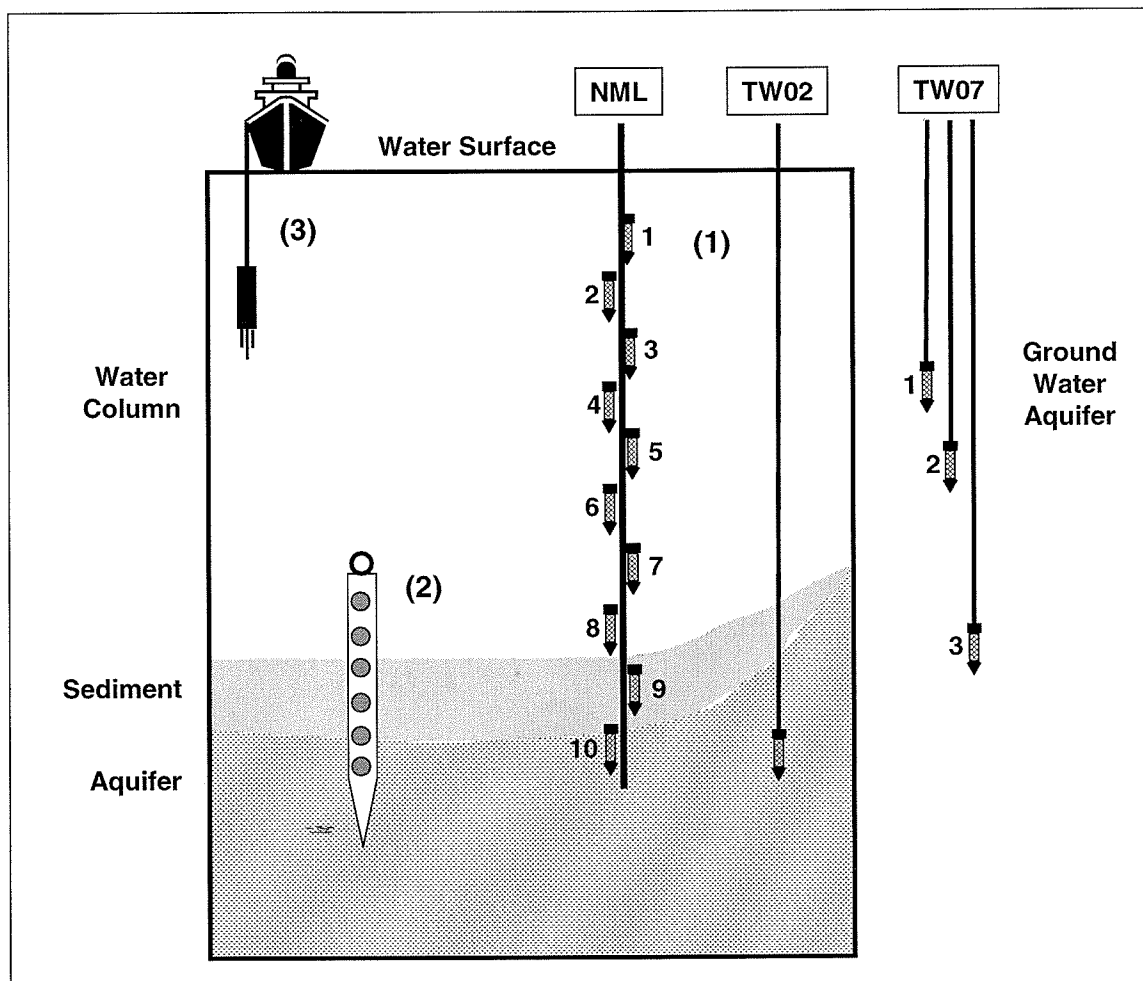
Several sampling strategies were employed in order to monitor the affects of ground water discharge into the HBHA Pond. Throughout the study period, water column samples were

collected at three locations within the north, central and south portions of the pond. In addition, periodic samples were also collected from the Atlantic Avenue Drainway inlet, the Hall's Brook inlet, and the HBHA Pond outlet. A permanent multi-level station with on-land sampling ports was also installed within the north end of the HBHA Pond during the March-April, 2000 field trip. This facilitated collection of depth-resolved water samples over closely spaced periods of time without the need to launch a boat. Finally, collection of pore water samples from shallow sediments was achieved through temporary installation of discrete multi-level samplers (DMLS) at select locations. All sampling locations within the HBHA Pond are displayed on Figure A.8 in Appendix A. A diagram illustrating the strategy to integrate ground water and surface water sampling is shown in Figure 2.

2.3.2 Sediments

Sediments were collected from the HBHA Pond (Figure A.9, Appendix A) employing two different approaches. The first approach involved use of Geoprobe® equipment to collect cores that penetrated through the sediment layer into the underlying aquifer. This was achieved from a boat by hand deploying a Geoprobe® core sampler. Sediment cores were sectioned in the field in order to obtain depth-resolved data at each sampling location. Sediment grab samples were also obtained via two methods: 1) hand sampling along near-shore locations, and 2) pumping unconsolidated sediment from the sediment-water interface at the bottom of the pond using a peristaltic pump. Sediment materials were characterized for total metals, total sulfur, and total organic carbon.

Figure 2. Idealized diagram of water sampling and characterization strategy for HBHA Pond: 1) permanent sampling points (tubing wells) for depth-resolved sampling of water column and adjacent aquifer, 2) diffusion samplers (DMLS) for depth-resolved sampling across sediment-aquifer interface, and 3) surface water vertical profiling throughout aerial extent of HBHA Pond.



2.4 HBHA Wetland and Wells G&H Wetland

Sediment samples were collected from the HBHA Wetland and Wells G&H Wetland (see Table F.6 for locations). Grab samples were collected from underneath the water surface, immediately placed in Ziplock bags, and frozen for shipment. Samples were maintained frozen prior to processing in a glove bag with an atmosphere of 97% N₂:3% H₂ v/v. Thawed samples were homogenized and split into two subsamples. One subsample was drained under moderate hand pressure and then allowed to dry at room temperature within the glove box. Select geochemical parameters and dissolved metals were analyzed on the isolated sediment pore water. Subsamples of the dried sediment were then subjected to leaching tests to assess arsenic release under oxic conditions. The chemical composition of the leaching solution was comparable to the average composition of shallow water within the HBHA Pond (specifically sampling location NML-2).

3.0 Extent of Arsenic Contamination

3.1 Ground Water

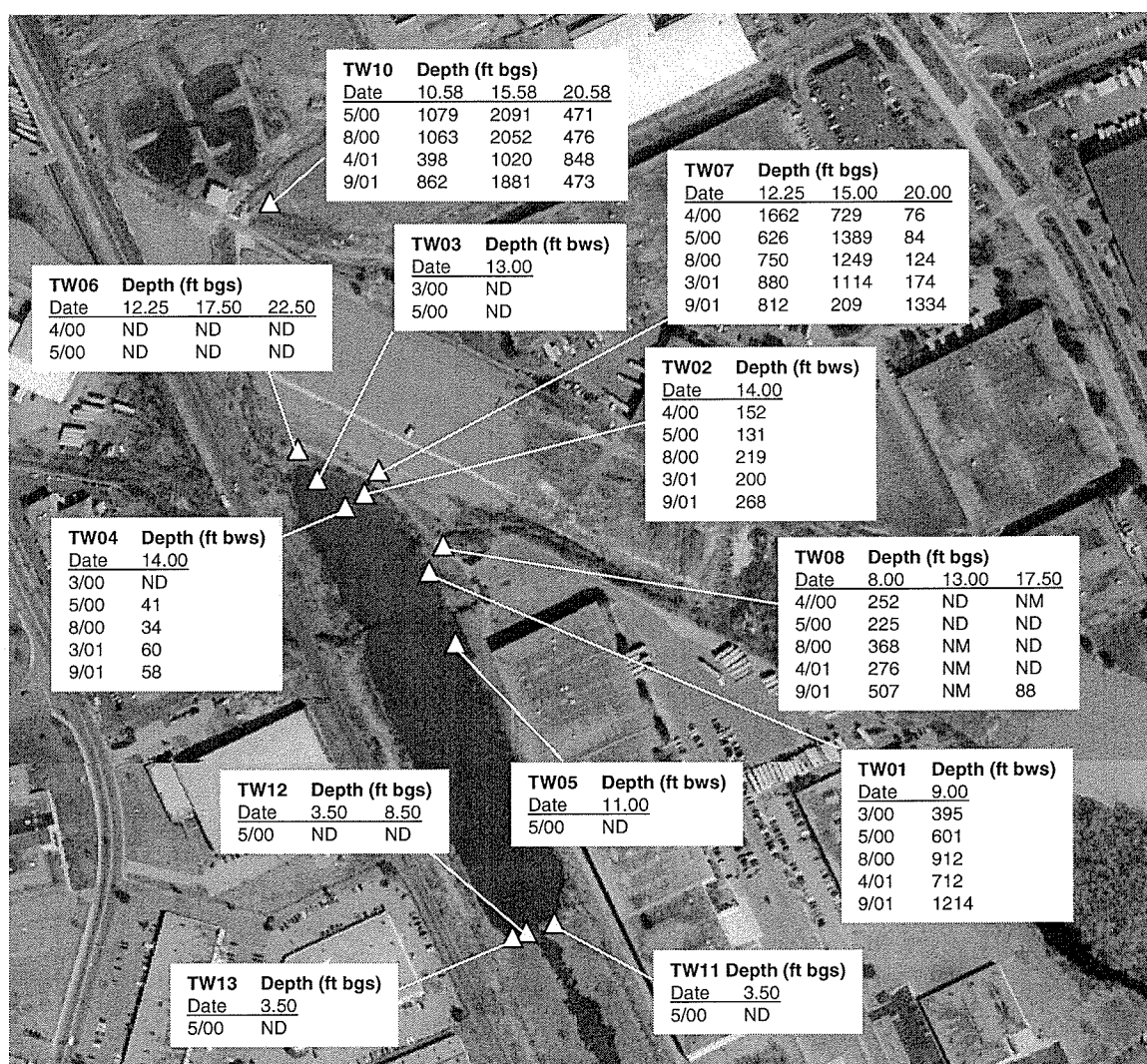
The results of ground water arsenic measurements at fixed monitoring locations from March 2000 to September 2001 are shown in Figure 3. The results of snap-shot monitoring locations A09, A15, A18, A19 (Figure 1) and fixed locations TW03, TW04, and TW06 indicate that there is not a significant source of arsenic in ground water along the western portion of the HBHA Pond. Only location TW04 had concentrations of arsenic above the analytical detection limit, and the concentration of arsenic was consistently <60 ppb. This is supported by ground-water data collected by USEPA Region 1 and the ISRT (O'Brien & Gere Engineers, Inc., 2002). In contrast, elevated concentrations of arsenic were consistently detected at locations TW01, TW02, TW07, and TW08. For these locations, the highest concentration observed for arsenic

was 1662 ppb at location TW07-1, which is a shallow ground-monitoring depth adjacent to the northeast bank of the HBHA Pond. The concentration of arsenic observed at these monitoring locations is consistent with observations at location TW10, which is upgradient from the HBHA Pond and situated between the Ground Water Treatment Building and the South Hidepile. While there are upward and downward fluctuations in the arsenic concentration at each monitoring location and depth, there is no consistent trend that supports an overall diminution in ground-water arsenic during this observation period. Comparison of the dissolved arsenic concentrations detected during this study to previous monitoring efforts dating back to 1990 indicate that there is a long term source of arsenic to ground-water that has not been eliminated by current site remedial efforts (Roux Associates et al., 1997).

Comparison of arsenic concentrations determined at snap-shot and fixed monitoring locations indicates that the focal point for arsenic discharge is along the eastern portion of the HBHA Pond. This discharge zone extends from the mid-point of the northern bank down to approximately the north exterior wall of the 36 Cabot Road Building (formerly owned by Digital). The predominance of arsenite among the species detected in ground water indicates that reducing conditions in the subsurface maintain arsenic mobility within the aquifer (see Appendices D and E). Based on one round of sampling, arsenic concentrations measured at fixed monitoring points at the southern edge of the HBHA Pond (TW11, TW12, TW13) indicate that there is insignificant arsenic discharge in shallow ground water down gradient to the HBHA Wetland. Thus, the monitoring data from the snap-shot and fixed monitoring points indicate that the HBHA Pond may intercept a significant fraction of ground-water arsenic derived from the Industri-Plex Superfund Site. This is supported by data from ground-water transects south of the

HBHA Pond down to Mishawaum Road completed by the ISRT (O'Brien & Gere Engineers, Inc., 2002).

Figure 3. Aerial distribution and time-dependent variability for total dissolved arsenic concentrations (ppb) detected in tubing wells established within the Industri-Plex Superfund site and GSIP Study Area. The designation for each tubing well location is shown; consult Figures A.4 and A.5 and Tables B.1 and B.2 in Appendices A and B, respectively. Depths are shown in feet below ground surface (ft bgs) and feet below water surface (ft bws) for tubing wells installed on land and within the HBHA Pond, respectively. Depths for tubing wells TW01, TW02, TW03, TW04, and TW05 were determined at the time of installation. NM = not measured, ND = not detected.



3.2 HBHA Pond Sediments

Bulk and trace metal concentrations for sediments collected within the HBHA Pond are documented in Appendix F. The aerial distribution and concentration of As, Pb, and Zn for a subset of these sediments is illustrated in Figure 4. This subset of samples represents shallow sediments collected from the sediment-water interface. The metal concentrations in this subset of samples range from 430-1680 ppm, 115-1180 ppm, and 583-17500 ppm for As, Pb and Zn, respectively. The highest concentrations of arsenic are generally located in the deepest portion of the HBHA Pond. However, the results shown in Figure 4 indicate that elevated levels of As are distributed throughout the HBHA Pond. The depth distribution of As, Pb and Zn in sediment cores is given in Tables F.1, F.2 and F.3 in Appendix F. In general, the highest concentration of these metals is associated with shallow sediments that have the highest concentrations of Fe, S and TOC.

Correlations between arsenic content and major sediment components are shown in Figure 5. The data presented include results for all samples listed in Appendix F. The values of total Fe, total S and TOC were determined directly by microwave-assisted acid digestion or x-ray fluorescence spectroscopy and sulfur/carbon coulometry. Sediments collected from locations WI01, WI02 and WI04 have an orangish-red hue and are produced from the rapid oxidation and precipitation of ferrous iron discharging into the HBHA Pond from shallow ground water seeps (see Figure F.1). Shallow sediments collected from the deeper portions of the HBHA Pond are black due to the high contents of iron sulfides and organic matter.

The arsenic content of sediments collected within the HBHA Pond is positively correlated with the total Fe content (Figure 5A). All Fe-As data pairs plot along a trend with little scatter with the exception of three of the oxic grab samples. These samples were collected

from the 'iron seep' area at the north end of the HBHA Pond (see Figure F.1). The iron content of these samples is exceptionally high, since they are composed primarily of the fine-grained precipitates that form from ferrous iron oxidation-precipitation. There is also a positive correlation between total S and TOC for all sediment samples (Figures 5B and 5C). The strong relationship between total Fe and As is preserved when results from down gradient wetland sediments are included in the plot, highlighting the important role of iron minerals in controlling arsenic partitioning to sediments (Figure 5A). Mass balance calculations based on sulfur measurements for HBHA Pond sediments indicate that Fe sulfides account for <50 % of the total amount of Fe. The remaining fraction of iron may be associated with iron carbonates, Fe-bearing clay minerals, organic matter or iron oxides. However, there is insufficient information collected as part of this study to determine the distribution of Fe minerals in HBHA Pond sediments. Other investigators have suggested that iron oxides persist in reducing sediments for this location, but these observations are as yet inconclusive (Aurilio et al., 1994; Hemond, 1995; Davis et al., 1996; Ahmann et al., 1997). HBHA Pond water column measurements discussed below indicate that a significant fraction of the iron oxides produced in this system are unstable under reducing conditions.

Figure 4. Arsenic, lead and zinc distribution within HBHA Pond sediments collected from sediment-water interface. Results shown for sediment cores NC01, CC02 and SC02 are for the first depth interval only. See Figure A.9 and Tables F.1-F.4 for sample identification. Results are reported in units of ppm on a dry mass basis.

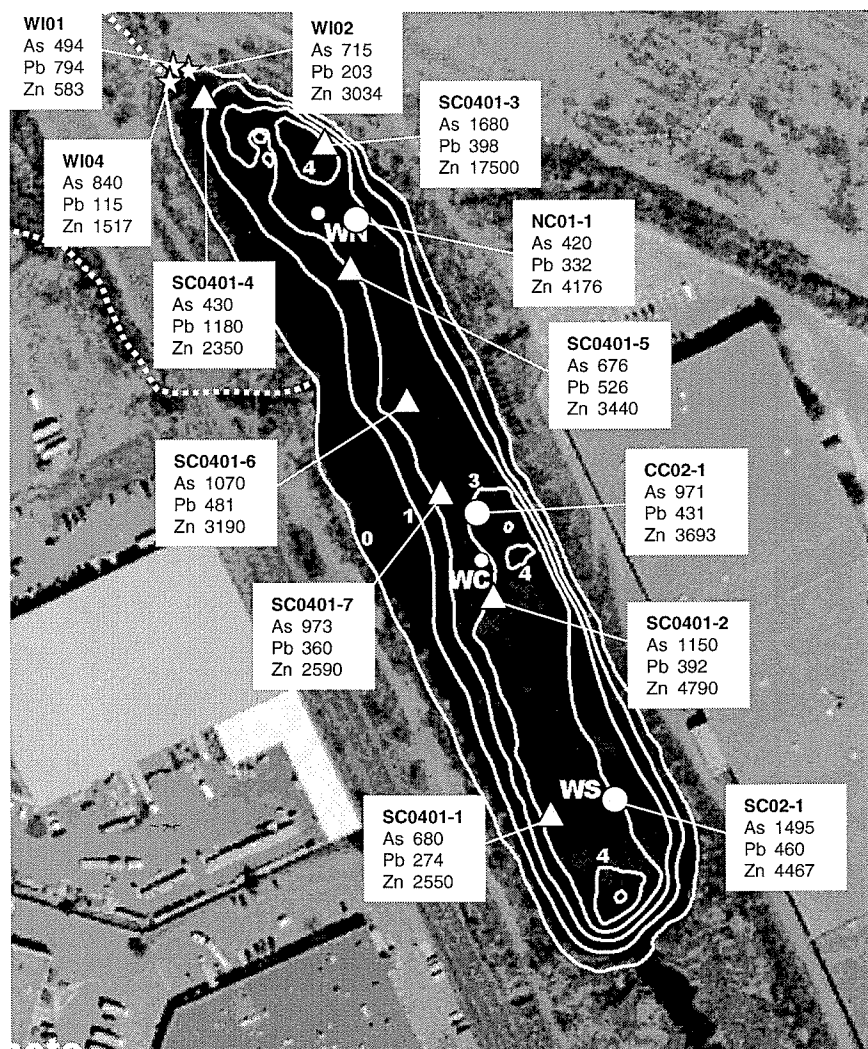
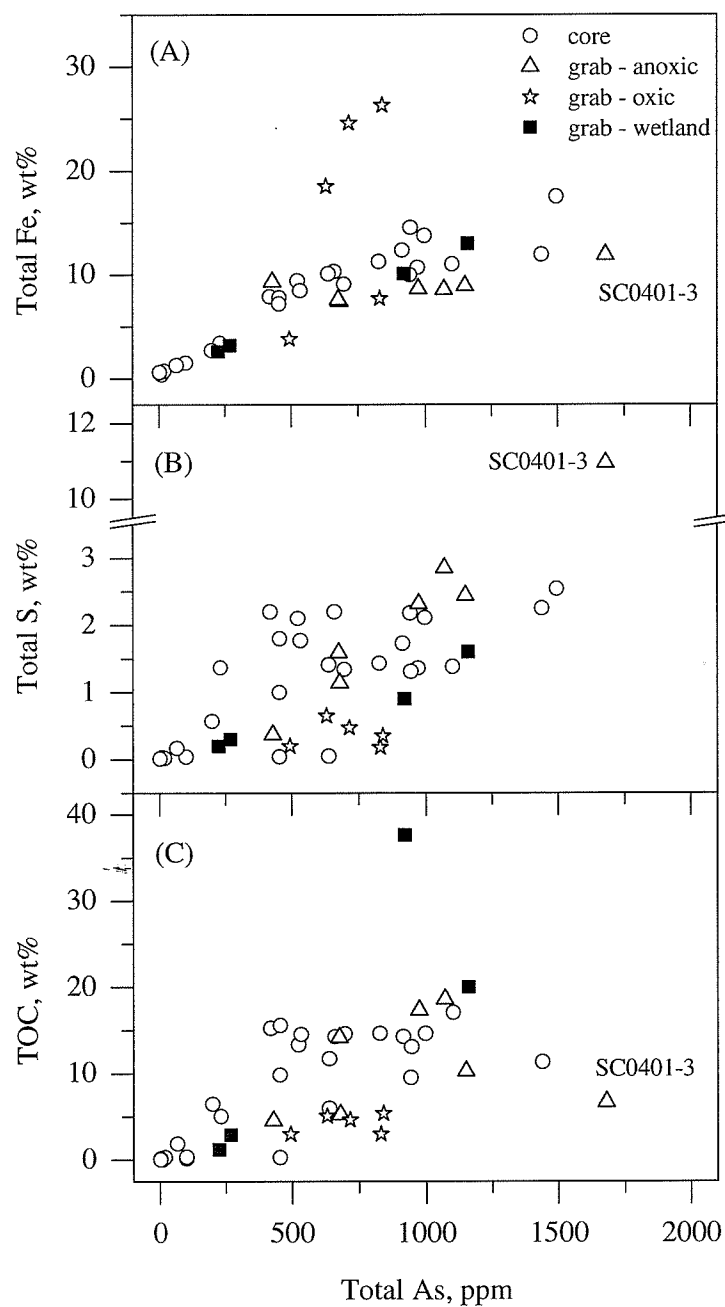


Figure 5. Correlations between sediment geochemical parameters and total arsenic content in sediments sampled from the HBHA Pond. Sample information is documented in the following locations: 1) core; Figure A.9 and Tables F.1-F.3, 2) grab – anoxic; Figure A.9 and Table F.4, 3) grab – oxic; Figure A.9 and Table F.4, and 4) grab – wetland; Table F.5. Symbol identifiers used in this figure correspond with those used in Figure A.9.



3.3 Surface Water – HBHA Pond

The results of monitoring water chemistry within the HBHA Pond are documented in Appendices C-E. A subset of these data is shown in Figures 6 and 7 below. Depth-resolved profiles for specific conductivity and dissolved arsenic at north, central and south sampling locations within the HBHA Pond (see Figure A.7) are shown in Figure 6. Values for these two chemical parameters were assessed for five dates over a period spanning from November 1999 to September 2001. The month and year of each sampling event is documented on the figure. Data for specific conductivity indicate that the HBHA Pond was chemically stratified during four of the five sampling dates. This is consistent with historical trends for this water body (Wick and Gschwend, 1998; Wick et al., 2000). Results for dissolved arsenic also show a general pattern of highest concentrations in the anoxic bottom water with a decrease to values typically <50 ppb in the shallow oxic waters. The highest concentration of arsenic (5043 ppb) was observed during September 2001 at a depth of 419 cm (13.7 ft) at the North Multi-level sampling station. However, elevated concentrations of dissolved arsenic were also observed within the central and south portions of the HBHA Pond with the highest observed values of 2170 ppb (central) and 2845 ppb (south) during September 2001. Since there is no evidence of a source of arsenic of this magnitude from ground-water discharge south of Hall's Brook, the elevated arsenic concentrations within the Central and South portions of the HBHA Pond are most likely associated with sediment dissolution.

The magnitude of sediment dissolution is illustrated in Figure 7. Time-dependent variations in specific conductivity and dissolved arsenic are shown for water samples collected from the North Multi-level sampling station following a large runoff event that occurred around March 31, 2001 (based on stream gage data at USGS station number 01102500 at Winchester,

MA). NML was designed to sample at ten depths, eight of which are positioned within the HBHA Pond water column and the remaining two located within the sediment layer and underlying aquifer, respectively. The relative position of sampling screens NML-1 to NML-10 with respect to the HBHA Pond water surface are shown to the right of the figure. The relative depths of screened intervals at tubing well TW07 are also shown. This shows that sampling depths NML-3 and NML-4 bracket sampling location TW07-1, sampling depth NML-5 coincides approximately with sampling location TW07-2, and sampling depth NML-8 coincides approximately with sampling location TW07-3. The relative position of NML and nearby tubing wells is also shown from an aerial perspective.

The specific conductivity depth profile at NML indicates that the large surface runoff event resulted in significant dilution within the HBHA Pond water column down to a depth of approximately 350 cm (11.5 ft). During the period of observation, the specific conductivity profile was re-established to a pre-runoff condition with time. Based on the monitoring dates, a steady-state profile was re-established again by May 14, 2001 and little variation outside of normal fluctuations was observed for subsequent sampling dates. The largest changes in specific conductivity were observed over a depth interval from 200 – 350 cm (6.6 – 11.5 ft). Significant changes were also observed for the dissolved arsenic depth profile over this period of observation. During the period April 5, 2001 to May 14, 2001, dissolved arsenic concentrations increased to the greatest extent over the depth interval 220 – 370 cm (7.2 – 12.1 ft). However, during the period May 14, 2001 to September 13, 2001 there was a significant increase in dissolved arsenic over the depth interval 220 – 420 cm (7.2 – 13.8 ft). A maximum dissolved arsenic concentration of 5043 ppb was observed at NML-8 (420 cm) on September 13, 2001. The concentrations of dissolved arsenic observed in the adjacent ground-water aquifer (tubing

well TW07) and the northern portion of the HBHA Pond water column over this period of observation are shown in Table 1.

Comparison of the behavior of specific conductivity and dissolved arsenic provide insight into the source of arsenic into the HBHA Pond water column. The time-dependent increase in dissolved arsenic with depth mimics the increase observed for specific conductivity during the period April 5, 2001 to May 14, 2001. The greatest change in both parameters is observed over the depth interval 220 – 370 cm (7.2 – 12.1 ft), of which the approximate location of maximum change is shown by the arrow in the left- and right-hand panels of Figure 7. The only source of water into the HBHA Pond with conductivity greater than 1000 $\mu\text{S}/\text{cm}$ is from site-derived ground water. Based on the shape of the dissolved As vertical profile on May 14, 2001, a significant fraction of the observed increase of dissolved arsenic during the period April 5, 2001 to May 14, 2001 appears to derive from ground-water discharge. However, during the period May 14, 2001 to September 14, 2001 there is a significant shift in the dissolved arsenic depth profile without a corresponding shift in the specific conductivity depth profile. The dissolved arsenic concentration observed at NML-8 on September 13, 2001 (5043 ppb) is significantly higher than the concentration observed at TW07-3 (1334 ppb). Examination of dissolved As concentrations observed for ground-water sampling locations TW02, TW03, TW04 and TW07 immediately adjacent to the NML sampling location reveals the lack of a potential ground-water source that could account for the As concentration observed at NML-8 on September 13, 2001. This indicates that there is an additional source of arsenic to the HBHA Pond water column.

The regular increase in dissolved arsenic with depth indicates that the additional source of dissolved arsenic is dissolution of arsenic-bearing solids within the reducing zone of the HBHA Pond water column down to the sediment-water interface. This is supported by the

observation that the dissolved arsenic concentration is much lower at screened intervals NML-9 and NML-10 on September 14, 2001 (269 and 209 ppb, respectively). Since the water column over the depth spanned from NML-5 to NML-8 remained anoxic during the period of observation, the source of arsenic is primarily dissolution of arsenic-bearing iron oxides. These iron oxides are derived from two potential sources: 1) transport of oxidic arsenic-rich iron oxides from the shallow near-shore portions of the HBHA Pond (e.g., see Appendix F, Figure F.1), and 2) deposition of arsenic-rich iron oxides following oxidation-precipitation of ferrous iron at the oxic-anoxic interface in the HBHA Pond water column (approximate location shown in Figure 7). A dissolved arsenic concentration of approximately 2000 ppb has consistently been observed at a depth greater than 250 cm (>8.2 ft) at the north, central and south surface water sampling stations throughout the period of this investigation (see Figure 6 and Figure A.7). The higher dissolved As concentration observed at depth on September 13, 2001 may be due to a large influx of As-bearing iron oxides from shallow near-shore sediments as a result of scouring during the large flow event at the end of March 2001. This is supported by the observed removal of a significant fraction of the orangish-red iron oxides that deposit near the outlet of the AAD following the large flow event.

However, it should be noted that the location of NML does not coincide with the north sampling station, and sampling depths NML-7 and NML-8 are actually in a deeper portion of the pond. There is no historical data to dispute that dissolved As concentrations observed on September 13, 2001 have not always occurred at this particular depth within the HBHA Pond prior to the large flow event at the end of March 2001. Dissolved arsenic concentrations from the northern portion of the HBHA Pond and TW07 are also shown for April 2000 and April 2, 2001 in Table 1. Instances in which the As concentration in the water column is lower than in

the adjacent aquifer for a given depth are indicative of 1) dilution following mixing of ground water and surface water and/or 2) loss of As due to uptake on iron oxides. However, instances in which the As concentration in the water column exceeds adjacent ground-water concentrations can be attributed to an additional source of arsenic. Again, since none of the adjacent ground-water sampling locations account for the As concentrations observed in the deeper portion of the HBHA Pond during September 2001, the most likely source of this additional As is from sediment dissolution. The significance of sediment dissolution as a source of dissolved arsenic to the HBHA Pond water column will be discussed in more detail below.